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THE NAUTICAL ALMANAC.

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Although the Nautical Almanacs of the world, at the present time, are of comparatively recent origin, they have grown from small beginnings, the tracing of which is not unlike that of the origin of species by the naturalist of the present day. Notwithstanding its familiar name it has always been designed rather for astronomical than for nautical purposes. Such a publication would have been of no use to the navigator before he had instruments with which to measure the altitudes of the heavenly bodies. The earlier navigators seldom ventured out of sight of land, and, during the night they are said to have steered by the "Cynosure" or constellation of the Great Bear, a practice which has brought the name of the contsellation into our language of the present day to designate an object on which all eyes are intently fixed. This constellation was a little nearer the pole in former ages than at the present time; still its distance was always so great that its use, as a mark of the northern point of the horizon, does not inspire us with great respect for the accuracy with which the ancient navigators sought to shape their course.

The Nautical Almanac of the present day had its origin in the Astronomical Ephemerides called forth by the needs of predictions of celestial motions both on the part of the astronomer and the citizen. So long as astrology had a firm hold on the minds of men, the positions of the planets were looked to with great interest. The theories of Ptolemy, although founded on a radically false system, neverthe-

less sufficed to predict the position of the sun, moon and planets with all the accuracy necessary for the purposes of the daily life of the ancients or the sentences of their astrologers. Indeed, if his tables were carried down to the present time, the positions of the heavenly bodies would be so few degrees in error that their recognition would be very easy. The times of most of the eclipses would be predicted within a few hours, and the conjunctions of the planets within a few days. Thus it was possible for the astronomers of the middle ages to prepare for their own use, and that of the people, certain rude predictions respecting the courses of the sun and moon and the aspect of the heavens, which served the purpose of daily life and perhaps lessened the confusion arising from their complicated calendars. In the signs of the zodiac and the different effects which follow from the sun and moon passing from sign to sign, still found in our farmers' almanacs, we have the dying traces of these ancient ephemerides.

The great Kepler was obliged to print an astrological almanac in virtue of his position as astronomer of the court of the King of Austria. But notwithstanding the popular belief that astronomy had its origin in astrology the astronomical writings of all ages seem to show that the astronomers proper never had any belief in astrology. To Kepler himself the necessity for preparing this almanac was a humiliation to which he submitted only through the pressure of poverty. Subsequent ephemerides were prepared with more practical objects. They gave the longitudes of the planets, the position of the sun, the time of rising and setting, the prediction of eclipses etc.

They have, of course, gradually increased in accuracy as the tables of the celestial motions were improved from time to time. At first they were not regular, annual publications, issued by governments, as at the present time, but the works of individual astronomers who issued their ephemerides for several years in advance, at irregular intervals. One man might issue one, two or half a dozen such volumes, as a private work, for the benefit of his fellows and each might cover as many years as he thought proper.

The first publication of this sort, which I have in my possession, is the Ephemerides of Manfredi, of Bonn, computed for the years 1715 to 1725, in two volumes.

Of the regular annual ephemerides the earliest, so far as I am aware, is the "*Connaissance des Temps*" or French Nautical Almanac. The first issue was in the year 1679, by Picard, and it has been continued without interruption to the present time. Its early numbers were, of

course, very small, and meagre in their details. They were issued by the astronomers of the French Academy of Science, under the combined auspices of the Academy and the Government. They included not merely predictions from the tables but also astronomical observations made at the Paris Observatory or elsewhere. When the Bureau of longitudes was created in 1795, the preparation of the work was entrusted to it and has remained in its charge until the present time. As it is the oldest, so, in respect at least to number of pages, it is the largest ephemeris of the present time. The astronomical portion of the volume for 1879 fills more than seven hundred pages, while the table of Geographical positions, which has always been a feature of the work, contains nearly 100 pages more.

The first issue of the British Nautical Almanac was that for the year 1767 and appeared in 1766. It differs from the French Almanac in owing its origin entirely to the needs of navigation. The British nation, as the leading maritime power of the world, was naturally interested in the discovery of a method by which the longitude could be found at sea. As most of my hearers are probably aware, there was, for many years, a standing offer by the British Government, of ten thousand pounds for the discovery of a practical and sufficiently accurate method of attaining this object. If I am rightly informed, the requirement was that a ship should be able to determine the Greenwich time within two minutes, after being six months at sea. When the office of Astronomer Royal was established in 1765, the duty of the incumbent was declared to be "to apply himself with the most exact care and diligence to the rectifying the Tables of the Motions of the Heavens, and the places of the Fixed Stars in order to find out the so much desired Longitude at Sea for the perfecting the Art of Navigation."

About the middle of the last century the lunar tables were so far improved, that Dr. Maskelyne considered them available for attaining this long wished for object. The method which I think was then, for the first time, proposed was the now familiar one of lunar distances. Several trials of the method were made by accomplished gentlemen who considered that nothing was wanting to make it practical at sea but a Nautical Ephemeris. The tables of the moon, necessary for the purpose, were prepared by Tobias Mayer of Gottingen, and the regular annual issue of the work was commenced in 1766, as already stated. Of the reward which had been offered three thousand pounds were paid to the widow of Mayer and three thousand pounds to the

celebrated mathematician Euler for having prepared the theorems used by Mayer in the construction of his tables. The issue of the Nautical Ephemeris was entrusted to Dr. Maskelyne. Like other publications of this sort this ephemeris has gradually increased in extent. During the first 60 or 70 years the data were extremely meagre, including only such as were considered necessary for the determination of positions.

In 1830 the subject of improving the Nautical Almanac was referred by the Lord Commissioners of the Admiralty to a committee of the Astronomical Society of London. A sub-committee, including eleven of the most distinguished astronomers and one scientific navigator made an exhaustive report recommending a radical re-arrangement and improvement of the work. The recommendations of this committee were first carried into effect in the Nautical Almanac for the year 1834. The arrangement of the Navigator's Ephemeris then devised has been continued in the British Almanac to the present time.

A good deal of matter has been added to the British Almanac during the forty years and upwards which have elapsed, but it has been gotten in rather by using smaller type and closer printing than by increasing the number of pages. The almanac for 1834 contains five hundred and seventeen pages and that for 1880 five hundred and nineteen pages. The general aspect of the page is now somewhat crowded, yet, considering the quantity of figures on each page the arrangement is marvelously clear and legible.

The Spanish *Almanaque Nautico* has been issued since the beginning of the century. Like its fellows it has been gradually enlarged and improved, in recent times, and is now of about the same number of pages with the British and American almanacs. As a rule there is less matter on a page, so that the data actually given are not so complete as in some other publications.

In Germany two distinct publications of this class are issued, the one purely astronomical, the other purely nautical.

The astronomical publication has been issued for more than a century under the title of "*Berliner Astronomisches Jahrbuch.*" It is intended principally for the theoretical astronomer, and in respect to matter necessary to the determinations of positions on the earth it is rather meagre. It is issued by the Berlin Observatory, at the expense of the government.

The companion of this work, intended for the use of the German marine, is the "*Nautisches Jahrbuch,*" prepared and issued under the

direction of the minister of commerce and public works. It is copied largely from the British Nautical Almanac, and in respect to arrangement and data is similar to our American Nautical Almanac, prepared for the use of navigators, giving, however, more matter, but in a less convenient form. The right ascension and declination of the moon are given for every three hours instead of for every hour; one page of each month is devoted to eclipses of Jupiter's satellites, phenomena which we never consider necessary in the nautical portion of our own almanac. At the end of the work the apparent positions of seventy or eighty of the brightest stars are given for every ten days, while it is considered that our own navigators will be satisfied with the mean places for the beginning of the year. At the end is a collection of tables which I doubt whether any other than a German navigator would ever use. Whether they use them or not I am not prepared to say.

The preceding are the principal astronomical and nautical ephemerides of the world, but there are a number of minor publications, of the same class, of which I cannot pretend to give a complete list. Among them is the Portuguese Astronomical Ephemeris for the meridian of the University of Coimbra, prepared for Portuguese navigators. I do not know whether the Portuguese navigators really reckon their longitudes from this point: if they do the practice must be attended with more or less confusion. All the matter is given by months, as in the solar and lunar ephemeris of our own and the British Almanac. For the sun we have its longitude, right ascension and declination, all expressed in arc and not in time. The equation of time and the sidereal time of mean noon complete the ephemeris proper. The positions of the principal planets are given in no case oftener than for every third day. The longitude and latitude of the moon are given for noon and midnight. One feature not found in any other almanac is the time at which the moon enters each of the signs of the zodiac. It may be supposed that this information is designed rather for the benefit of the Portuguese landsman than of the navigator. The right ascensions and declinations of the moon and the lunar distances are also given for intervals of twelve hours. Only the last page gives the eclipses of the satellites of Jupiter. The Fixed Stars are wholly omitted.

An old ephemeris, and one well known in astronomy, is that published by the Observatory of Milan, Italy, which has lately entered upon the second century of its existence. Its data are extremely meagre and of no interest whatever to the navigator. The greater part of the volume is taken up with observations at the Milan Observatory.

Since taking charge of the American Ephemeris I have endeavored to ascertain what nautical almanacs are actually used by the principal maritime nations of Europe. I have been able to obtain none except those above mentioned. As a general rule I think the British Nautical Almanac is used by all the northern nations, as already indicated. The German Nautical *Jahrbuch* is principally a reprint from the British. The Swedish navigators, being all well acquainted with the English language, use the British Almanac without change. The Russian Government however prints an explanation of the various terms in the language of their own people and binds it in at the end of the British Almanac. This explanation includes translations of the principal terms used in the heading of pages, such as the names of the months and days, the different planets, constellations and fixed stars and the phenomena of angle and time. They have even an index of their own in which the titles of the different articles are given in Russian. This explanation occupies, in all, seventy-five pages—more than double that taken up by the original explanation.

One of the first considerations which strikes us in comparing these multitudinous publications, is the confusion which must arise from the use of so many meridians. If each of these southern nations, the Spanish and Portuguese for instance, actually use a meridian of their own, the practice must lead to great confusion. If their navigators do not do so, but refer their longitudes to the meridian of Greenwich, then their almanacs must be as good as useless. They would find it far better to buy an ephemeris referred to the meridian of Greenwich than to attempt to use their own. The northern nations, I think, have all begun to refer to the meridian of Greenwich, and the same thing is happily true of our own marine. We may, therefore, hope that all commercial nations will, before long, refer their longitudes to one and the same meridian, and the resulting confusion be thus avoided.

The preparation of the American Ephemeris and Nautical Almanac was commenced in 1849, under the superintendence of the late Rear Admiral, then Lieutenant Davis. The first volume, as you are all probably aware, was that for the year 1855. Both in the preparation of that work and in the connected work of mapping the country, the question of the meridians to be adopted was one of the first importance, and received great attention from Admiral Davis, who made an able report on the subject. Our situation was, in some respects, peculiar, owing to the great distance which separated us from Europe, and the uncertainty of the exact difference of longitude between the two con-

tinents. It was hardly practicable to refer longitudes in our own country to any European meridian. The attempt to do so would involve continual changes as the trans-Atlantic longitude was from time to time corrected. On the other hand, in order to avoid confusion in navigation, it was essential that our navigators should continue to reckon from the meridian of Greenwich. The trouble arising from uncertainty of the exact longitude does not affect the navigator, because, for his purpose, astronomical precision is not necessary.

The wisest solution was probably that embodied in the Act of Congress, approved September 28th, 1850, on the recommendation of Lieut. Davis, if I mistake not. "The meridian of the Observatory at Washington shall be adopted and used as the American meridian for all astronomical purposes, and the meridian of Greenwich shall be adopted for all nautical purposes." The execution of this law necessarily involves the question "What shall be considered astronomical and what nautical purposes?" Whether it was from the difficulty of deciding this question, or from nobody's remembering the law, the latter has been practically a dead letter. Surely, if there is any region of the globe which the law intended should be referred to the meridian of Washington, it is the interior of our own country, yet, notwithstanding the law, all acts of Congress relating to the territories have, so far as I know, referred everything to the meridian of Greenwich and not to that of Washington. Even the maps issued by our various surveys are referred to the same trans-Atlantic meridian. The absurdity culminated in a local map of the City of Washington and the District of Columbia, issued by private parties, in 1861, in which we find even the meridians passing through the City of Washington referred to a supposed Greenwich.

This practice has led to a confusion which may not be evident at first sight, but which is so great and permanent that it may be worth explaining. If, indeed, we could actually refer all our longitudes to an accurate meridian of Greenwich in the first place; if, for instance, any western region could be at once connected by telegraph with the Greenwich Observatory, and thus exchange longitude signals, night after night, no trouble or confusion would arise from referring to the meridian of Greenwich. But this, practically, cannot be done. All our interior longitudes have been and are determined differentially by comparison with some point in this country. One of the most frequent points of reference used this way has been the Cambridge Observatory. Suppose then a surveyor at Omaha makes a telegraphic longitude de-

termination between that point and the Cambridge Observatory. Since he wants his longitude reduced to Greenwich, he finds some supposed longitude of the Cambridge Observatory from Greenwich and adds that to his own longitude. Thus what he gives is a longitude actually determined, plus an assumed longitude of Cambridge, and unless the assumed longitude of Cambridge is distinctly marked on his maps, we may not know what it is.

After a while a second party determines the longitude of Ogden from Cambridge. In the mean time, the longitude of Cambridge from Greenwich has been corrected, and we have a longitude of Ogden which will be discordant with that of Omaha, owing to the change in the longitude of Cambridge. A third party determines the longitudes of, let us suppose, St. Louis from Washington, he adds the assumed longitudes of Washington from Greenwich what may not agree with either of the longitudes of Cambridge and gets his longitude. Thus we have a series of results for our western longitude all nominally referred to the meridian of Greenwich, but actually referred to a confused collection of meridians, nobody knows what. If the law had only provided that the longitude of Washington from Greenwich should be invariably fixed at a certain quantity say 77° 3′ this confusion would not have arisen. It is true that the longitude thus established by law might not have been perfectly correct, but this would not cause any trouble nor confusion. Our longitude would have been simply referred to a certain assumed Greenwich, the small error of which would have been of no importance to the navigator or astronomer. It would have differed from the present system only in that the assumed Greenwich would have been invariable instead of dancing about from time to time as it has done under the present system. You understand that when the astronomer, in computing an interior longitude, supposes that of Cambridge from Greenwich to be a certain definite amount, say $4^h\ 44^m\ 30,^s$ what he actually does is to count from a meridian just that far east of Cambridge. When he changes the assumed longitude of Cambridge he counts from a meridian further east or further west of his former one: in other words he always counts from an assumed Greenwich, which changes its position from, time to time, relative to our own country.

Having two meridians to look after, the form of the American ephemeris, to be best adapted to the wants both of navigators and astronomers, was necessarily peculiar. Had our navigators referred their longitudes to any meridian of our own country the arrangement

of the work need not have differed materially from that of foreign ones. But being referred to a meridian far outside our limits and at the same time designed for use within those limits, it was necessary to make a division of the matter. Accordingly the American Ephemeris has always been divided into two parts; the first for the use of navigators, referred to the meridian of Greenwich, the second for that of astronomers, referred to the meridian of Washington. The division of the matter without serious duplication is more easy than might at first be imagined. In explaining it, I will take the ephemeris as it now is, with the small changes which have been made from time to time.

One of the purposes of any ephemeris, and especially of that of the navigators, is to give the position of the heavenly bodies at equi-distant intervals of time, usually one day. Since it is noon at some point of the earth all the time, it follows that such an ephemeris will always be referred to noon at some meridian. What meridian this shall be is purely a practical question, to be determined by convenience and custom. Greenwich noon, being that necessarily used by the navigator, is adopted as the standard, but we must not conclude that the ephemeris for Greenwich noon is referred to the meridian of Greenwich in the sense that we refer a longitude to that meridian. Greenwich noon is $18^h\ 51^m\ 48^s$, Washington mean time; so the ephemeris which gives data for every Greenwich noon may be considered as referred to the meridian of Washington giving the data for $17^h\ 51^m\ 48^s$, Washington time, every day. The rule adopted therefore is to have all the ephemerides which refer to absolute time, without any reference to a meridian, given for Greenwich noon, unless there may be some special reason to the contrary. For the needs of the navigator and the theoretical astronomer these are the most convenient epochs.

Another part of the ephemeris gives the position of the heavenly bodies, not at equi-distant intervals, but at transit over some meridian. For this purpose the meridian of Washington is chosen for obvious reasons. The astronomical part of our ephemeris therefore gives the positions of the principal fixed stars, the sun, moon, and all the larger planets at the moment of transit over our own meridian.

The third class of data in the ephemeris comprises phenomena to be predicted and observed. Such are eclipses of the sun and moon, occultations of fixed stars by the moon, and eclipses of Jupiter's satellites. These phenomena are all given in Washington mean time as being most convenient for observers in our own country. There is a partial exception however in the case of eclipses of the sun and moon. The

former are rather for the world in general than for our own country, and it was found difficult to arrange them to be referred to the meridian of Washington without having the maps referred to the same meridian. Since, however, the meridian of Greenwich is most convenient outside of our own territory, and since but a small portion of the eclipses are visible within it, it is much the best to have the eclipses referred entirely to the meridian of Greenwich. I am the more ready to adopt this change because when the eclipses are to be computed for our own country the change of meridians will be very readily understood by those who make the computation.

It may be interesting to say something of the tables and theories from which the astronomical ephemerides are computed. To understand them completely it is necessary to trace them to their origin. The problem of calculating the motions of the heavenly bodies and the changes in the aspect of the celestial sphere was one of the first with which the students of astronomy were occupied. Indeed, in ancient times, the only astronomical problems which could be attacked were of this class, for the simple reason that without the telescope and other instruments of research it was impossible to form any idea of the physical constitution of the heavenly bodies. To the ancients the stars and planets were simply points or surfaces in motion. They might have guessed that they were globes like that on which we live but they were unable to form any theory of the nature of these globes. Thus, in the Almagest of Ptolemy, the most complete treatise on the ancient astronomy which we possess, we find the motions of all the heavenly bodies carefully investigated and tables given for the convenient computation of their positions. Crude and imperfect though these tables may be they were the beginnings from which those now in use have arisen.

No radical change was made in the general principles on which these theories and tables were constructed until the true system of the world was propounded by Copernicus. On this system the apparent motion of each planet in the epicycle was represented by a motion of the earth around the sun, and the problem of correcting the position of the planet on account of the epicycle was reduced to finding its geocentric from its heliocentric position. This was the greatest step ever taken in theoretical astronomy, yet it was but a single step. So far as the materials were concerned and the mode of representing the planetary motions, no other radical advance was made by Copernicus. Indeed it is remarkable that he introduced an epicycle which was not

considered necessary by Ptolemy in order to represent the inequalities in the motions of the planets around the sun.

The next great advance made in the theory of the planetary motion was the discovery by Kepler of the celebrated laws which bear his name. When it was established that each planet moved in an ellipse having the sun in one focus it became possible to form tables of the motions of the heavenly bodies much more accurate than had before been known. Such tables were published by Kepler in 1632, under the name of Rudolphian tables, in memory of his patron, the emperor Rudolph. But the laws of Kepler took no account of the action of the planets on each other. It is well known that if each planet moved only under the influence of the gravitating force of the sun its motion would accord rigorously with the laws of Kepler, and the problems of theoretical astronomy would be greatly simplified. When therefore the results of Kepler's laws were compared with ancient and modern observations it was found that they were not exactly represented by the theory. It was evident that the elliptic orbits of the planets were subject to change, but it was entirely beyond the power of investigation, at that time, to assign any cause for such changes. Notwithstanding the simplicity of the causes which we now know to produce them, they are in form extremely complex. Without the knowledge of the theory of gravitation it would be entirely out of the question to form any tables of the planetary motions which would at all satisfy our modern astronomers.

When the theory of universal gravitation was propounded by Newton he showed that a planet subjected only to the gravitation of a central body, like the sun, would move in exact accordance with Kepler's laws. But by his theory the planets must attract each other and these attractions must cause the motions of each to deviate slightly from the laws in question. Since such deviations were actually observed it was very natural to conclude that they were due to this cause, but how shall we prove it? To do this with all the rigor required in a mathematical investigation it is necessary to calculate the effect of the mutual action of the planets in changing their orbits. This calculation must be made with such precision that there shall be no doubt respecting the results of the theory. Then its results must be compared with the best observations. If the slightest outstanding difference is established there is something wrong and the requirements of astronomical science are not satisfied. The complete solution of this problem was entirely beyond the power of Newton. When his methods of research

were used he was indeed able to show that the mutual action of the planets would produce deviations in their motions of the same general nature with those observed, but he was not able to calculate these deviations with numerical exactness. His most successful attempt in this direction was perhaps made in the case of the moon. He showed that the sun's disturbing force on this body would produce several inequalities the existence of which had been established by observation, and he was also able to give a rough estimate of their amount, but this was as far as his method could go. A great improvement had to be made, and this was effected not by English but by continental mathematicians.

The latter saw clearly that it was impossible to effect the required solution by the geometrical mode of reasoning employed by Newton. The problem, as it presented itself to their minds, was to find algebraic expressions for the positions of the planets at any time. The latitude, longitude and radius vector of each planet are constantly varying, but they each have a determined value at each moment of time. They may therefore be regarded as functions of the time, and the problem was to express these functions by algebraic formulæ. These algebraic expressions would contain, besides the time, the elements of the planetary orbits to be derived from observation. The time which we may suppose to be represented algebraically by the symbol t, would remain as an unknown quantity to the end. What the mathematician sought to do was to present the astronomer with a series of algebraic expressions containing t as an indeterminate quantity, and so, by simply substituting for t any year and fraction of a year whatever, 1600, 1700, 1800, for example, the result would give the latitude, longitude or radius vector of a planet.

The problem as thus presented was one of the most difficult we can conceive of, but the difficulty was only an incentive to attacking it with all the greater energy. So long as the motion was supposed purely elliptical, so long as the action of the planets was neglected, the problem was a simple one, requiring for its solution only the analytic geometry of the ellipse. The real difficulties commenced when the mutual action of the planets was taken into account. It is, of course, out of the question to give any technical description or analysis of the processes which have been invented for solving the problem; but a brief historical sketch may not be out of place. A complete and rigorous solution of the problem is out of the question, that is, it is impossible by any known method, to form an algebraic expression for the co-ordinates

of a planet which shall be absolutely exact in a mathematical sense In whatever way we go to work the expression comes out in the form of an infinite series of terms, each term being, on the whole, a little smaller as we increase the number. So, by increasing the number of these various terms, we can approach nearer and nearer to a mathematical exactness, but can never reach it. The mathematician and astronomer have to be satisfied when they have carried the solution so far that the neglected quantities are entirely beyond the powers of observation.

Mathematicians have worked upon the problem in its various phases for nearly two centuries, and many improvements in detail have, from time to time, been made, but no general method, applicable to all cases, has been devised. One plan is to be used in treating the motion of the moon, another for the interior planets, another for Jupiter and Saturn, another for the minor planets, and so on. Under these circumstances it will not surprise you to learn that our tables of the celestial motions do not, in general, correspond in accuracy to the present state of practical astronomy. There is no authority and no office in the world whose duty it is to look after the preparation of the formulæ I have described. The work of computing them has been almost entirely left to individual mathematicians whose taste lay in that direction, and who have sometimes devoted the greater part of their lives to calculations on a single part of the work. As a striking instance of this, the last great work on the "Motion of the Moon," that of Delaunay, of Paris, involved some fifteen years of continuous hard labor.

Hansen, of Germany, who died five years ago, devoted almost his whole life to investigations of this class and to the development of new methods of computation. His tables of the moon are those now used for predicting the places of the moon in all the ephemerides of the world.

The only successful attempt to prepare systematic tables for all the large planets is that completed by Le Verrier, just before his death; but he used only a small fraction of the material at his disposal, and did not employ the modern methods, confining himself wholly to those invented by his countrymen about the beginning of the present century. For him Jacobi and Hansen had lived in vain.

The great difficulty which besets the subject arises from the fact that mathematical processes alone will not give us the position of a planet, there being seven unknown quantities for each planet which must be determined by observations. A planet, for instance, may

move in any ellipse whatever, having the sun in one focus, and it is impossible to tell what ellipse it is, except from observation. The mean motion of a planet, or its period of revolution, can only be determined by a long series of observations, greater accuracy being obtained the longer the observations are continued. Before the time of Bradley, who commenced work at the Greenwich Observatory about 1750, the observations were so far from accurate that they are now of no use whatever unless in exceptional cases. Even Bradley's observations are in many cases far less accurate than those made now. In consequence, we have not heretofore had a sufficiently extended series of observations to form an entirely satisfactory theory of the celestial motions.

As a consequence of the several difficulties and drawbacks when the computation of our ephemeris was started, in the year 1849, there were no tables which could be regarded as really satisfactory in use. In the British Nautical Almanac the places of the moon were derived from the tables of Burckhardt published in the year 1812. You will understand, in a case like this, no observations subsequent to the issue of the tables are made use of; the place of the moon of any day, hour and minute of Greenwich time, mean time, was precisely what Burckhardt would have computed nearly a half a century before. Of the tables of the larger planets the latest were those of Bouvard, published in 1821, while the places of Venus were from tables published by Lindenau in 1810. Of course such tables did not possess astronomical accuracy. At that time, in the case of the moon, completely new tables were constructed from the results reached by Professor Airy in his reduction of the Greenwich observations of the moon from 1750 to 1830. These were constructed under the direction of Prof. Pierce and represented the places of the moon with far greater accuracy than the older tables of Burckhardt. For the larger planets corrections were applied to the older tables to make them more nearly represent observations before new ones were constructed. These corrections however have not proved satisfactory, not being founded on sufficiently thorough investigations. Indeed, the operation of correcting tables by observation, as we would correct the dead reckoning of a ship, is a makeshift, the result of which must always be somewhat uncertain, and it tends to destroy that unity which is an essential element of the astronomical ephemeris designed for permanent future use. The result of introducing them, while no doubt an improvement on the old tables, has not been all that should be desired. The general lack of unity

in the tables hitherto employed is such that I can only state what has been done by mentioning each planet in detail.

For Mercury new tables were constructed by Prof. Winlock, from formulæ published by Le Verrier, in 1846. These tables have, however, been diviating from the true motion of the planet, owing to the motion of the perhelion of Mercury subsequently discovered by Le Verrier himself. They are now much less accurate than the newer tables published by Le Verrier ten years later.

Of Venus new tables were constructed by Mr. Hill, in 1872. They are more accurate than any others, being founded on later data than those of Le Verrier, and are therefore satisfactory so far as accuracy of prediction is concerned.

The places of Mars, Jupiter and Saturn are still computed from the old tables, with certain necessary corrections to make them better represent observations.

The places of Uranus and Neptune are derived from new tables which will probably be sufficiently accurate for some time to come.

For the moon Pierce's tables have been employed up to the year 1882 inclusive. Commencing with the ephemeris for the years 1883 Hansen's tables are introduced with corrections to the mean longitude founded on two centuries of observation.

With so great a lack of uniformity, and in the absence of any existing tables which have any other element of unity than that of being the work of the same authors it is extremely desirable that we should be able to compute astronomical ephemerides from a single uniform and consistent set of astronomical data. I hope, in the course of years, to render this possible.

When our ephemeris was first commenced, the corrections applied to existing tables rendered it more accurate than any other. Since that time, the introduction into foreign ephemerides of the improved tables of Le Verrier have rendered them, on the whole, rather more accurate than our own. In one direction, however, our ephemeris will hereafter be far ahead of all others. I mean in its positions of the fixed stars. This portion of it is of particular importance to us, owing to the extent to which our Government is engaged in the determination of positions on this continent, and especially in our western territories. Although the places of the stars are determined far more easily than those of the planets, the discussion of star positions has been in almost as backward a state as planetary positions. The errors of old observers have crept in and been continued through two generations

of astronomers. A systematic attempt has been made to correct the places of the stars for all systematic errors of this kind, and the work of preparing a catalogue of stars which shall be completely adapted to the determination of time and longitude, both in the fixed observatory and in the field, is now approaching completion. The catalogue cannot be sufficiently complete to give places of the stars for determining the latitude by the zenith telescope, because for such a purpose a much greater number of stars is necessary than can be incorporated in the ephemeris.

From what I have said, it will be seen that the astronomical tables, in general, do not satisfy the scientific condition of completely representing observations to the last degree of accuracy. Few, I think, have an idea how unsystematically work of this kind has hitherto been performed. Until very lately the tables we have possessed have been the work of one man here, another there, and another one somewhere else, each using different methods and different data. The result of this is that there is nothing uniform and systematic amongst them and that they have every range of precision. This is no doubt due in part to the fact that the construction of such tables, founded on the mass of observation hitherto made, is entirely beyond the power of any one man. What is wanted is a number of men of different degrees of capacity, all co-operating on a uniform system, so as to obtain a uniform result, like the astronomers in a large observatory. The Greenwich observatory presents an example of co-operative work of this class extending over more than a century. But it has never extended its operations far outside the field of observation, reduction and comparison with existing tables. It shows clearly, from time to time, the errors of the tables used in the British Nautical Almanac, but does nothing further, occasional investigations excepted, in the way of supplying new tables. An exception to this is a great work on the theory of the moon's motion, in which Professor Airy is now engaged.

It will be understood that several distinct conditions not yet fulfilled, are desirable in astronomical tables; one is that each set of tables shall be founded on absolutely consistent data; for instance, that the masses of the planets shall be the same throughout. Another requirement is that this data shall be as near the truth as astronomical data will suffice to determine them. The third is that the results shall be correct in theory. That is, whether they agree or disagree with observations, they shall be such as result mathematically from the adopted data.

Tables completely fulfilling these conditions are still a work of the future. It is yet to be seen whether such co-operation as is necessary to their production can be secured under any arrangement whatever.

DISCUSSION.

In the course of the discussion which followed this paper, the reader expressed some doubts whether the navigators of the several southern nations of Europe actually used their own meridians, and inquired whether the naval officers present could give information on this point.

LIEUTENANT-COMMANDER THOMAS NELSON. The French reckon longitude from the meridian of Paris; the Spaniards from Cadiz; Portuguese from Lisbon, and the Brazilians from Rio de Janeiro.

Russians, Germans, Austrians, Danes, Swedes and Dutch all reckon longitude from Greenwich, and I believe that most all other maritime nations of any importance do the same.

CAPTAIN R. L. LAW. I would ask the Professor, if, since we commenced the publication of a Nautical Almanac, it has not caused an improvement to be made in the English Almanac? Have they not learned something from looking over ours?

PROFESSOR NEWCOMB. That is hard to say. I do not think they would admit having learned or adopted anything from ours, nor have we any right to say that they have done so. Great improvements have been made in the British Nautical Almanac since ours commenced, and, while a competition may have stimulated them, I would not say that we have in any way guided them. The most obvious effect of the competition was to reduce the price of their almanac one half, a result which may not be considered especially desirable.

LIEUTENANT LONGNECKER. Have the Portuguese such complete charts that they can refer to them and tell how far they are from Lisbon at any given point?

LIEUTENANT COMMANDER THOMAS NELSON. I think not. I am of opinion that they have but very few of their own charts in use for navigating purposes, and probably use British Admiralty or French charts.

LIEUTENANT LONGNECKER. Suppose you meet a Portuguese ship in mid ocean and ask her what longitude she is in from Lisbon, can she tell you?

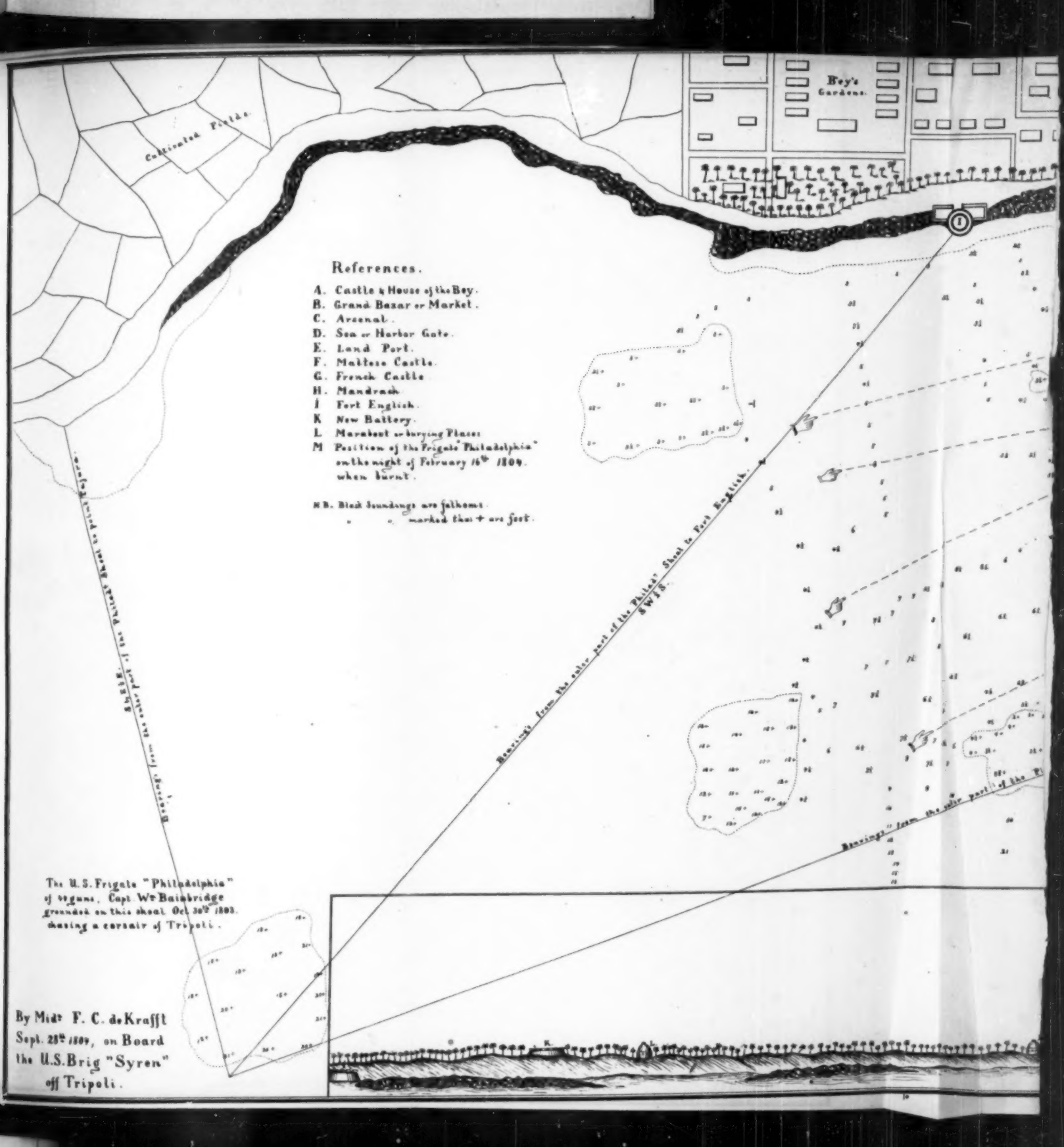
LIEUTENANT-COMMANDER THOMAS NELSON. I cannot say positively, but I think in that case she would probably not give you her longitude from Lisbon; more likely from Greenwich or Paris, according to the chart she was using.

The CHAIRMAN. The Russians use their own chart in computing distances, as well as the longitude from Greenwich. That is my impression.

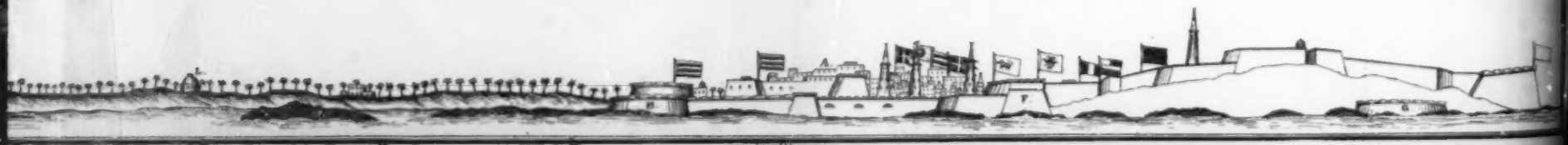
LIEUTENANT-COMMANDER THOMAS NELSON. The meridian of St. Petersburg is marked on most Russian charts, as well as that of Greenwich, I presume, for convenience in ascertaining by inspection the meridian distance of any place from St. Petersburg, and perhaps more particularly for finding the meridian distance between any two places in their own country. For navigating purposes, however, they use the meridian of Greenwich.

COMMANDER MC CORMICK. I move that this meeting tender a vote of thanks to Professor Newcomb, for the very interesting paper he has read to us. The subject on its face looked like a dry one, but he has certainly succeeded in making it a very interesting one.

The motion of Commander Mc Cormick was unanimously agreed to.


Bey's Gardens.
Cultivated Fields.
References.
A. Castle & House of the Bey.
B. Grand Bazar or Market.
C. Arsenal.
D. Sea or Harbor Gate.
E. Land Port.
F. Maltese Castle.
G. French Castle.
H. Mandrash.
I Fort English.
K New Battery.
L Marabout or burying Places.
M Position of the Frigate "Philadelphia" on the night of February 16th 1804. when burnt.
N.B. Black Soundings are fathoms.
marked thus + are feet.
Bearings from the outer part of the Philad.a Shoal to Fort English.
S.W.½S.
Bearings from the outer part of the Philad.a Shoal to the Point of Rocks.
Bearings from the outer part of the P
The U.S. Frigate "Philadelphia" of 44 guns. Capt. Wm Bainbridge grounded on this shoal Oct. 31st 1803. chasing a corsair of Tripoli.
By Midn F. C. de Krafft Sept. 28th 1804, on Board the U.S. Brig "Syren" off Tripoli.

A View of Tripoli in Barbary.



(Scale of one Geographical mile.)

MAP OF TRIPOLI.

The accompanying map of the harbor of Tripoli was sketched on the spot in 1804, by Mr. F. C. de Krafft, a Midshipman on board the Brig Syren. The original is now in the possession of his son, Captain J. C. P. de Krafft, U. S. Navy, who has kindly allowed it to be lithographed, to illustrate Commodore Preble's Journal. It is valuable not only on account of its accuracy, which may be tested by comparison with the Admiralty chart, but also from its great historical interest, being the independent testimony of an eye-witness, and confirming many statements in Commodore Preble's narrative. All the important points referred to in the narrative will be found on the chart,—Fort English, the new fort built by the American prisoners, the round water battery to the west, and the mole-forts. The details of the action of the 3rd of August are given, as they appeared to Midshipman de Krafft. There is also a profile view of the harbor. I cannot help adding that I think the Institute extremely fortunate in being able to present such an illustration of a historical paper, and to publish so valuable a sketch, after it has lain in private hands for three quarters of a century.—J. R. S.